BEFORE THE
FEDERAL COMMUNICATIONS COMMISSION
WASHINGTON, D.C. 20554

In the matter of	)	
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Mitigation of Orbit Debris	)	IB Docket No. 02-54
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COMMENTS OF
L'GARDE, INC.

1. L'Garde, Inc. (hereinafter referred to as "L'Garde"), pursuant to Section 1.405 of the Commission's Rules and Regulations, respectfully submits these comments in response to the Commission's Notice of Proposed Rule Making, IB Docket No. 02-54, released March 18, 2002. L'Garde agrees that it is important to address issues relating to the mitigation of space debris at this time.

L'Garde is an operating aerospace company focused on providing low-mass deployable space structures to the space community. We believe that a certain class of these devices could be quite useful for controlling and eliminating debris from orbit and thus help to mitigate the damage that can be caused by such debris, particularly in low Earth orbit.

L'Garde is pleased to offer our technical comments regarding the nature of the rules that should be adopted by the Commission. We address primarily herein our understanding of the state-of-the-art of inflatable and deployable technologies that will be useful in deorbiting space systems after their missions have been terminated, either by planned operations or system failure. These technical means may not have been explicitly contemplated by the Commission or the public.

I. PRELIMINARY STATEMENT

2. L'Garde is a private company, incorporated under the laws of the State of California, with all facilities in Tustin, California. The company designs and supplies a variety of low-mass deployable space structures and related avionics, and is particularly adept at engineering and producing inflatable systems. Our staff has extensive experience with government and commercial projects, both open and classified/proprietary. We produce systems that operate in the space environment (which ultimately could contribute to the space debris concern) and develop hardware and systems that could be used to dispose of space debris, and thus we feel qualified and compelled to comment in these proceedings on this important and urgent subject.

II. BACKGROUND

A. Fundamental Technical Aspect of Orbital Debris

3. The NPRM correctly notes, "Atmospheric drag on orbiting objects decreases dramatically as the orbital altitude of the object increases." [1] The Commission also properly claims that the orbital lifetime of space systems is affected by varying solar activity. The orbital lifetime of a space object is also a function of its ballistic coefficient (object mass divided by projected surface area). It is well known that at a given orbit altitude, lower values of ballistic coefficient will decrease orbital lifetime as a result of

[1] NPRM at §7.

increased drag acting on the object.[2] As will be will be discussed, many of L'Garde's systems rely on this property, and it will be shown that significant benefit could accrue to the space community if practical methods of removing space debris from Earth orbit using this property and the resultant effects could be found.

B. Development of U.S. Policy and Regulations Concerning Orbital Debris

4. L'Garde supports the adoption of the four objectives developed under U.S. Governments Standards and Practices for the control of debris.[4] Our comments in this proceeding will primarily be related to objective #4 addressing post-mission disposal of space systems.

C. International Aspects

5. L'Garde recognizes and supports the role the FCC could play in the international enforcement of the Outer Space Treaty and related international agreements and an extension of this role for the intended purpose of mitigating the space-debris concern seems appropriate.

III. DISCUSSION

A. FCC Statutory Authority Concerning Orbital Debris

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[2] Wertz, J.R. and Larson, W.J., "Space Mission Analysis and Design," Fig. 8-4, Space Technical Library, 1999, p 210.

[2] NPRM at §11

[4] NPRM at §11

6. L'Garde believes it would be an appropriate role for the Commission to assume the added responsibility within the government of establishing and administering orbit-debris policy.

7. L'Garde observes that although launch-vehicle booster stages are not often cause for concern, spent launch-vehicle upper stages are frequently placed (left) into orbits where operating spacecraft reside, creating a collision and debris concern. And though efforts are made to actively deplete residual propellants in these stages (primarily liquid-propellant systems), in a few cases the past couple of decades a supposedly inert spent stage spontaneously exploded, creating a serious debris cloud. L'Garde suggests that a concerted government program to address the orbital debris concern—whether caused by spacecraft or launch systems—from a single-agency standpoint would be the preferred approach, rather than dividing the responsibility between multiple agencies.

B. Elements of Orbital Debris Mitigation

8. In the Notice, the FCC sought general comments regarding the economic impact of the adoption of debris-mitigation procedures on the operation of commercial spacecraft. [7] As Ecliptic is not a satellite system operator, we will refrain from commenting in this area, particularly as it relates to high Earth-orbiting or geostationary satellites. However, regarding communication systems and constellations that use orbits below 900 km, we will provide evidence in this area showing that low-cost technologies are available which enable system operators to meet the 25-year criteria for orbit removal

[5] NPRM at § 30
[6] NPRM at § 32
[7] NPRM at §35

suggested by this NRPM.[8] Ecliptic thus believes little to no economic hardship will be introduced should the Commission adopt its proposed rules to de-orbit spacecraft in this category. Indeed, the proposed technology is non-propulsive and would also allow the system operator to earn revenue from the spacecraft until its natural end-of-life.

9. The Notice notes the emergence of very small satellite system designs and seeks comments on whether such systems call into question the adequacy of economic incentives alone.[9] Ecliptic believes this issue is a particularly important consideration in these proceedings. Members of the Ecliptic staff are among the pioneers of the small satellite movement and have considerable experience with "nanosat" and "microsat" technologies. The applicability of very small satellite systems to the general solution of satellite communications problems must be acknowledged. Both reliability and capacity enhancement can be addressed simultaneously by increasing the number of satellites in a "nano" constellation. Further, the overall manufacturing costs for the space segment can be minimized through mass production. Even creative methods to launch an entire constellation of very small satellites with a single, low-cost launch vehicle have been found.[10] Unfortunately, in terms of space debris, the economic incentives run counter to the need to remove expended satellites from orbit. The number of spacecraft that optimize some communications scenarios could be in the thousands, their size may be smaller than can be observed with ground-based radar and the unit cost of these spacecraft is very low. Spacecraft in this size/mass category cannot practically have a propulsion system to remove themselves from orbit. Additionally, may such spacecraft

[8] NPRM at §12
[9] NPRM at §38
[10] King, J.A., Beidleman, N.J., "Method and Apparatus for Deploying a Satellite Network," U.S. Patent No. 5,199,672, April 6, 1993.

designs do not even include an attitude control system accurate enough to point a propulsion system for re-entry, should it exist. The only means of removing spacecraft of this size and in this quantity from orbit is to limit the allowable altitude of the constellation so that atmospheric re-entry within a calculable period of time is assured. Ecliptic suggests that, for this class of spacecraft and when the satellite constellation count is greater than (approximately 100), the re-entry after completion of mission rule be reduced to 5 years. Since there is no way of knowing when a given member of the constellation will fail (and since the reliability of individual spacecraft can be lower without impacting the overall system reliability) it is more likely that space debris will be generated early in the system lifetime. Ecliptic further recommends that spacecraft of this size category (regardless of the constellation size) be limited to altitudes of no higher than 625 km at perigee and further the ballistic coefficient of such spacecraft be 100 kg/m^2 or greater. We make note that it is the combination of the spacecraft's perigee altitude and its ballistic coefficient that determines its orbital lifetime and the uncertainty of the time of re-entry.

10. The Commission seeks comment regarding whether it should change its rules and practices regarding spacecraft flight profiles.[11] We find that the FCC rules requiring applicants to provide orbital information (such as the orbital elements for each space station) are generally helpful. For example, should particular LEO orbits become very popular and become populated by a large number of spacecraft, it would assist spacecraft system operators planning new missions, if a data base detailing this required information were publicly accessible. Ecliptic would note, however, that current state-of-the-art practices do not allow specification of the Keplerian orbital elements of spacecraft with

sufficient accuracy to predict or avoid the collision of two space objects. The Keplerian elements for any space object along with a time specify where an object is in space at that particular epoch. It is then possible to *propagate* these elements forward in time to predict where the same object will be in the future. This is, however, not a completely precise science. Errors in propagating the objects elements forward by even one day would result in an error considerably larger that the object itself. This implies that, at present, we are not able to accurately forecast a space collision. It is possible to determine that two object will pass quite close to one another, however. So, while orbital information may be useful in planning so as to minimize the probability of collisions, in the case of constellations, collision avoidance in a dynamic environment is not currently practical. In summary, Ecliptic would only recommend the Commission additionally require in the appropriate portions of CFR 47, that satellites licensed to use the radio spectrum by the FCC provide full, classical, Keplerian orbital elements for the spacecraft after launch and on a periodic basis after launch. We would recommend that these element sets be cataloged and be made available to the pubic in an easily usable format. In fact, this task is already the responsibility of the North American Air Defense (NORAD), an element of the Department of Defense. The parameters used, however, employ a format specialized for DoD purposes and the information is not generally made available to the public. This process would be most effective if the information could be made available via an FCC website (or equivalent). It should be the responsibility of each space station licensee to provide this information to the Commission on a timely and periodic basis and this information should then be incorporated into the publicly accessible database. This information could be cross checked with NORAD data if

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[11] NPRM at §41 to §44 and §47 to §50.

resources allow. Finally on this matter, we support the Commission's proposal to continue to allow applicants to select the orbital elements for their space systems, given the existence of the database reference above.

11. In the Notice at §49 the Commission specifically concludes, "non-geostationary satellite systems should disclose in license applications the tolerance within which orbital parameters would be maintained, so that generally affected third parties can evaluate any collision risk." Ecliptic would like to point out that many non-geostationary systems do not include propulsion or orbit maintenance means of any kind. Such spacecraft operators could only provide an estimation of how the spacecraft orbital elements are expected to change with time. Without periodic updates of these elements, tolerances associated with the satellites instant orbit location will continue to increase. We believe it *would* be economically harmful to many low-cost space missions if they were required to accommodate technical means to maintain their spacecraft's orbital elements within a tolerance band. For many projects like these, such a requirement would be quite disruptive. Further, as per our comments at 10, we do not believe current means of determining a satellite's position in space and propagating its position into the future are sufficiently accurate to assure avoidance of collision by means *of selection of an initial operating orbit*. In addition, we do not believe the orbits of current spacecraft, even with accurate propulsive means, can be adjusted with sufficient accuracy to avoid (or for that matter, cause) collisions with other space objects. We are not suggesting that rendezvous technology (i.e., spacecraft equipped with ranging or radar devices) is not possible; however, for missions with other intended applications, such apparatus, if imposed, would be cost prohibitive. We do acknowledge that many satellites now rely on

GPS for maintaining working Keplerian elements, in addition to Radar, ranging and other metric tracking schemes. This fact, however, does not alter our opinion that *practical* prediction and avoidance of collision events is not yet feasible.

12. In the Notice, the Commission seeks comment on whether it would be appropriate to adopt the post-mission guideline or portions of the guideline, as FCC rules. Further, the Commission seeks comment on technology developments that may affect end-of-life procedures.[12] Ecliptic wishes to comment on both of these areas by means of offering a consolidated argument. We feel the Commission has correctly recognized the importance of altitude "regimes" in their efforts to deal with orbit debris mitigation. It is of primary importance to recognize that objects at orbit altitudes exceeding 900 km [13] have lifetimes that exceed the event horizon for all practical mission planning and debris evaluation and management methodologies. We would not take specific issue with the Commission's 25 year rule-of-thumb as a practical limit for the elimination of debris from orbit or its transfer to suitably established *graveyard* orbits. We, however, feel the FCC can require more of spacecraft missions with initial orbits below 900 km, given the current state-of-the-art in low-cost technologies capable of modifying a space object's ballistic coefficient and hence, its orbital lifetime.[14] Spacecraft having perigees in higher

[12] NPRM at §54, §55 and §57.

[13] Wertz, J.R. and Larson, W.J., "Space Mission Analysis and Design," Fig. 8-4, Space Technical Library, 1999, p 210. Notice that for an object in a 900 km circular orbit the lifetime of a space object with a ballistic coefficient of 20 Kg/m^2 will re-enter in approximately 110 years. Extrapolation of the information from this figure suggests that if the ballistic coefficient of an object in the same orbit were reduced to approximately 5 Kg/m^2, the lifetime of the space object could be reduced to less than 25 years.

[14] An alternative to using a propulsion system to reduce the perigee altitude of a space object would be to use an inflatable device (balloon), released at the end-of-life of a given spacecraft. The balloon dramatically decreases the ballistic coefficient of the space object and its time to re-entry. The balloon may also be vapor-deposited with a metal coating causing the surface to be highly radar-reflective which, in turn, increases the object's radar cross-section. This could be of significant value for very small spacecraft that may be otherwise particularly problematic for skin-tracking radar. If the package used to deploy the balloon were autonomous from the primary spacecraft (including the power supply for the deployment

than 900 km and lower than 2000 km may be the most problematic. This altitude regime includes the orbits used for some constellation missions and includes some popular polar and sun-synchronous mission orbits. Spacecraft missions in this altitude regime would either have to decrease the perigee of their post-mission orbits to below 900 km (AND modify their ballistic coefficient) or would have to increase the perigee to about 2000 km and enter the first of the proposed graveyard (storage) orbits. There is no issue regarding the second graveyard (storage) orbit (perigee altitudes between 20,700 km and 35,300 km). This orbit regime is stable for extremely long times and is not a popular altitude range. Very few spacecraft occupy it.

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mechanism) and contained a very low-power identifying transponding beacon, it would have many of the characteristics of a flight termination system used by launch vehicles. A system of this type would not only accelerate the re-entry of the space object but would greatly improve the government's ability to positively identify and locate the object. Balloon systems of the size class suggested above and having similar surface properties have been demonstrated to have lifetimes long enough to prove the feasibility of this concept. (See http://www.lgarde.com/programs/ocse.html). De-orbit systems of this type promise to be extremely cost-effective, making it possible for even small spacecraft to employ them for post-mission debris removal.

As an example of the advantage of such a system, assume a spacecraft operating at an altitude of 650 km, having a mass of 100 Kg and assume it is a cube with a side dimension of 0.5 m. An inflatable balloon package is attached to the spacecraft that weighs 2.5 Kg and inflates to a diameter of 4 meters. The drag coefficient (Cd) of the spacecraft itself might be approximately 3.5 while the drag coefficient for the balloon is approximately 2.0. The minimum projected surface area of the cube is 0.25 m^2. The maximum ballistic coefficient of the spacecraft is given by m/Cd*A, where m is the spacecraft mass, A is the minimum projected surface area of the spacecraft into the velocity vector and Cd is the drag coefficient (dimensionless constant ranging in value between approximately 2 and 4). For the spacecraft, prior to balloon deployment the ballistic coefficient = (100+2.5)/4*(.25)= **102.5 Kg/m^2**. After balloon deployment the ballistic coefficient = $102.5/(2*(3.14)(4.0/2)^2) + 4(.5)^2 = 102.5/26.1$ **= 3.9 Kg/m^2** . Again, using Figure 8-4 from Wertz and Larson, the lifetime of the spacecraft before re-entry and without the drag balloon deployed would be approximately 50 years. After balloon deployment we estimate the configuration would re-enter in 0.5 years (i.e. six months). If the initial orbit had been 900 km, the lifetime of the spacecraft without balloon deployment would be approximately 1000 years. After deployment the lifetime of the system would be about 25 years. This last case sets a kind of upper bound for this particular satellite mass class, if we limit the balloon diameter to 4 meters based on the mass fraction of the de-orbit system to the total spacecraft mass.

13. Ecliptic believes GEO spacecraft represent a special case for orbital debris consideration. Because of the station-keeping requirements specified by the ITU and by CFR 47, Part 25.210(j) of the Commission's rules, it is necessary for geostationary spacecraft to periodically correct their orbit for both north-south and east-west drift, to an accuracy of ±0.05° in both directions from the nominal orbit slot location. A spacecraft that can satisfy these constraints can easily remove itself from GEO to the 3rd graveyard (storage) orbit recommended by the Commission. In other words, all spacecraft capable of operating for extended lifetimes on station at GEO are also capable of modifying their orbit appropriately to enter the storage orbit, provided only that sufficient propellant for the operation is budgeted and in fact, exists in the tanks. The 25-year post-mission disposal period proposed by the NPRM even allows for various forms of electric propulsion to be employed in the final orbit transition for geostationary satellites.

14. The Notice raises issues about the applicability of these proposed rule changes to experimental satellite (Part 5) and amateur satellite (Part 97) authorizations.[15] Ecliptic understands that these two classes of space system are *the* most cost constrained. It is our opinion that ultra small spacecraft of all types should be restricted to very low orbits (See our comments at 9.). This should include satellites authorized under Part 5 and Part 97. For spacecraft operating between 625km and 900 km it may be possible for even low cost missions to modify their ballistic coefficient as we have addressed above. For spacecraft operating in orbits between 900 km and 2000 km it is unlikely that Part 5 or Part 97 space vehicles will be able to effectively remove themselves from orbit within 25 years after their mission termination. It would be cost prohibitive to require this class

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[15] NPRM at §63

of mission to meet the requirements proposed by this NPRM and we feel it would be very harmful to the creative process so well demonstrated by such licensees to deny them the opportunity to use these orbits. For this reason we believe special allowance should be made in this altitude range for these licensees. We have no comment regarding higher storage orbits, except to note that many experimental and amateur satellites actually do operate in the proposed storage orbits. However, for the special case of the geostationary orbit, should spacecraft licensed under Part 5 or Part 97 be authorized to use either geostationary or geosynchronous orbits, removal of the space object at the end of life to a higher "graveyard" orbit should be feasible since maintaining a station or even a 24 hour synchronous period requires station-keeping ability. Therefore, removal from the GEO orbit should be feasible even for these licensees.

IV. CONCLUSION

15. Ecliptic believes that we have raised issues in our comments that require further evaluation and public debate. The issues associated with the establishing broad-sweeping rules will effect all non-government users of the space environment. This should be done with great care, considering the impact on all classes of space system. We note that space systems vary in cost from a few thousand to many billion U.S. dollars. The impact of the proposed rules of this NPRM will have very different consequences depending on which end of the cost spectrum a given space system occupies. We applaud the Commission's efforts in directly confronting the difficult issues associated with space debris (identification and removal). We support the government initiative to take action on this matter now. We do feel, however, that there

are many technical issues that need to be better understood (by the government and the public) prior to adopting formal rules via a Report and Order. We respectfully suggest this NPRM should be downgraded to an NOI so that more time and thought can be given to this matter. Ecliptic believes the public interest is best served, concerning this universal issue, by establishing a better technical and business awareness as to how space debris impacts all users of the space environment.